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Quantitative Assessment of Oceanic Squid by Means of Jigging Surveys*

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Abstract There are many kinds of squid and cuttlefish in the oceans of the world, and the stock sizes of some are presumed to be large. However, few attempts have been made to quantitatively assess standing stocks. In Japan, the commercial yield ranges from 400,000 to 900,000 metric tons annually, accounting for about 50 to 80% of the total cephalopod catch in the world.

Jigging surveys have been conducted since 1971 in the Sea of Japan and since 1973 in the Pacific Ocean off Japan. Their purpose has been to assess the abundance of oceanic squid. The stock size index (N) and the density index (F) for *Todarodes pacificus*, *Ommastrephes bartrami*, and *Onychoteuthis borealijaponica* were calculated for the Pacific from 1968 to 1979 and for the Sea of Japan from 1971 to 1979. N and F correspond reasonably well to periodic changes in the annual yield (Y) of *T. pacificus* in the Pacific and the Sea of Japan. Since Y is presumed to correspond well to abundance, the results of these surveys give rough estimates of *T. pacificus* abundance. Changes in N and F for *O. bartrami* and *O. borealijaponica* do not show good correspondence with Y , probably because the study area covers only a part of the range of the two species.

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The equation relating F and Y for *T. pacificus* and *O. bartrami* combined is

$$Y(\text{tons}) = 10,500 F + 16,300 \quad (r = 0.972).$$

This relationship might be used as a first approximation for expected yield, but to make a precise assessment of the abundance of these oceanic squids it will be necessary to accumulate more biological data on their distribution and migration and to adjust the grid surveys accordingly.

Introduction

About 500 nominal species in 30 families of squid and cuttlefish exist in the oceans of the world (Okutani, 1977). They are diverse in form and nature. Some are active, strong animals while others live a more or less drifting life. They are a major prey item for nektonic fish, marine mammals, and birds, and they play important roles in the marine biotic community. However, many important details of their biology have not been clarified. Overall stock sizes are believed to be very large (Clarke, 1966; Gulland, 1970; Voss, 1973).

In Japan, cephalopods are an important fishery resource. Annual yield varied from 400,000 to 880,000 metric tons between 1960 and 1964. The Japanese common squid, *Todarodes pacificus*, accounts for about 70% of the total cephalopod catch.

There have been large fluctuations in the annual yield of *T. pacificus*. Catches were below 200,000 tons before 1946, but since then there has been a rapid increase, reaching a peak of 670,000 tons in 1968 with a gradual decrease since then (Fig. 1). Most *T. pacificus* are caught by jigging (Araya, 1967; Okutani, 1977). The squid fishing fleet is large, consisting of 31,877 boats of less than 30 gross tons, 1,831 medium boats of 30 to 99 tons, and 186 large boats of 100 to 499 tons (1973 to 1977). Most of the yield is caught by the latter two size groups.

Scientific studies of *T. pacificus* began about 1950. Much information has accumulated since then about its population structure, distribution, migration, growth and lifespan, and reproduction (Soeda, 1956; Hamabe, 1961; Watanabe, 1965; Araya, 1967, 1976;

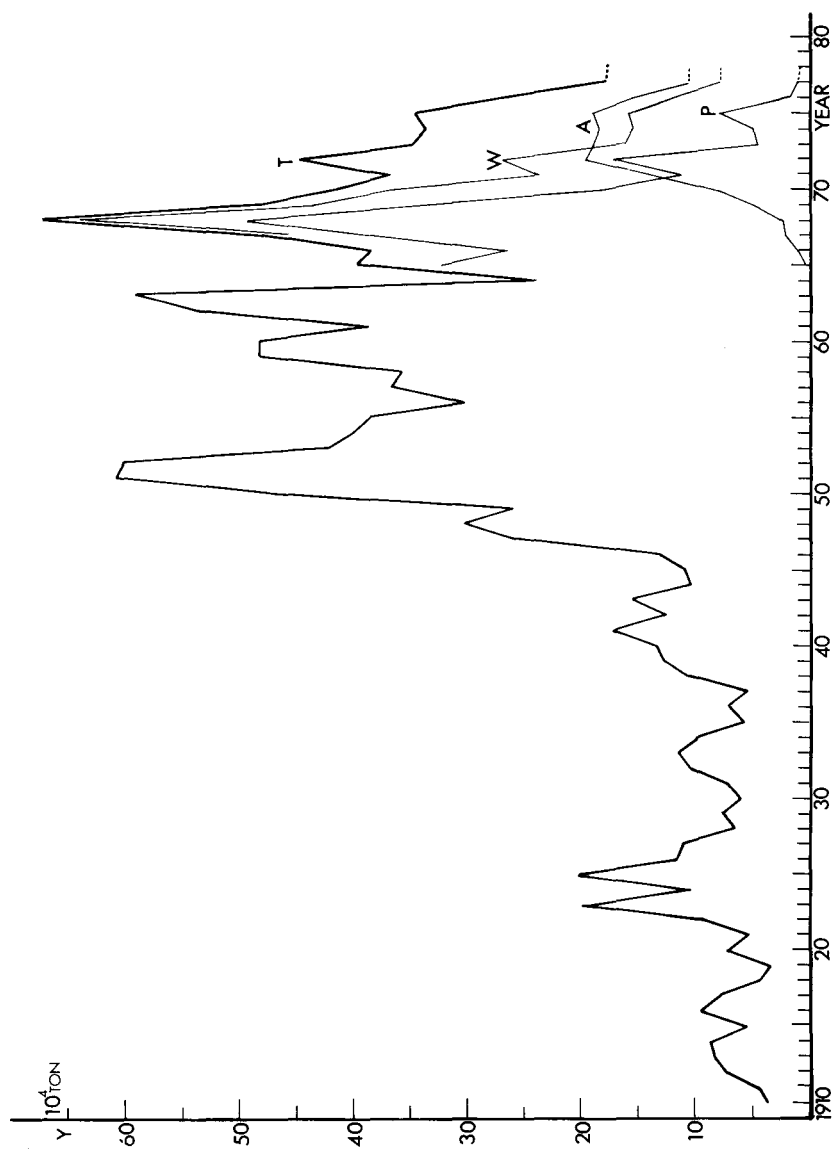


Figure 1. Annual yield (Y in metric tons) of the common squid *T. pacificus* in Japan. T, total; W, winter population; A, autumn population; P, in the waters off the Pacific coast of northeastern Japan.

Ito, 1972; Murata et al., 1973; Kasahara, 1978). Based on this information, fisheries research laboratories and prefectural fisheries experimental stations began to issue fisheries forecasts for this species in 1965. They now forecast stock size, total yield, location of fishing grounds, etc., and release these data to the public. In 1974, fishermen began to catch *O. bartrami* on a large scale and the annual yield is increasing rapidly.

The purpose of this paper is to assess the abundance of oceanic squid such as *T. pacificus* and *O. bartrami* in the waters around Japan, based on the results of jigging surveys by several research vessels.

Methods and Procedure of Grid Survey

The grid survey project was begun in 1971 for the Sea of Japan and in 1973 for the Pacific. Surveys were carried out twice a year, in spring and in autumn. The study areas were east of 130°E and between 36° and 45°N in the Sea of Japan (Kasahara, 1978), and west of 152°E and between 37° and 45°N in the Pacific (Murata et al., 1976). The purpose was to determine the stock size, the migration patterns, the formation of fishing grounds for *T. pacificus*, and to contribute to accurate fisheries forecasting. The Japan Sea Regional Fisheries Research Laboratory (Nisuiiken) is responsible for the program in the Sea of Japan, while the Hokkaido Regional Fisheries Research Laboratory (Hokusuiken) covers the Pacific (in cooperation with prefectural fisheries experimental stations and fisheries high schools).

Test squid jigging was carried out by 6–12 research vessels, for 2–10 hours at each grid point, during a period of 5–10 days. All of the sampling was performed by automatic jigging machines (Igarashi et al., 1968) at night using fish lamps. Squid jigs were lowered primarily to depths between 50 and 70 m. It was assumed that the abundance of squid was proportional to the number caught per jigging machine per hour, despite differences in lamp power and in the number of jigging machines per ship. Stock size index (N) and density index (F) of squid were calculated, based on the results of these grid surveys and the method in Table 1 (Murata et al., 1976; Kasahara, 1978).

Table 1

Stock size index (N) and density index (F) of three oceanic squids based on the grid survey in the waters off the Pacific coast of northeastern Japan in August–September of 1973 (From Murata et al., 1976).

Class of CPUE	<i>T. pacificus</i>		<i>O. bartrami</i>		<i>O. borealijaponica</i>	
	A_i	N_i	A_i	N_i	A_i	N_i
0	750	0	528	0	886	0
0 ~ 0.9	158	79	50	25	74	37
1.0 ~ 4.9	153	459	121	363	83	249
5.0 ~ 9.9	16	120	74	555	29	218
10.0 ~ 29.9	6	120	103	2,060	11	220
30.0 ~ 49.9	0	0	125	5,000	0	0
50.0 ~ 99.9	0	0	77	5,775	0	0
100.0 ~ 149.9	0	0	5	625	0	0
$\Sigma A_i, \Sigma N_i$	1,083	778	1,083	14,403	1,083	724
F	0.72		13.30		0.67	

A_i = number of $10' \times 10'$ squares of latitude and longitude within each contoured level of CPUE (number of squid per jigging machine per hour).

$N_i = A_i \times$ mid-class value of CPUE

$A = \Sigma A_i$ $N = \Sigma N_i$ $F = N/A$

(example: for *T. pacificus*, the number of squares with a CPUE between 10.0 and 29.9 is 6 ($=A_i$). The mid-class value is 20; thus $N_i = 6 \times 20 = 120$.)

Results

T. pacificus in the Waters Around Japan

According to Araya (1967), Ito (1972), and others, the population structure, the migration, and the lifespan of *T. pacificus* are summarized as follows:

There are three subpopulations of *T. pacificus*, each with different patterns of growth, maturity, migration, and breeding period. They are called winter, autumn, and summer populations. Their main spawning ground is the waters southwest of Japan. They migrate northward in spring and summer, and southward in autumn and winter. Adults are about 25 cm in mantle length, and about 300 g in body weight. Their lifespan is about one year.

Of these three subpopulations, the winter population has the widest distribution. It migrates as far north as the southern Kuril

Islands on the Pacific side, and north to 50° or 51°N in the Sea of Japan. This population is densely distributed in coastal waters and accounted for the greatest part of the total *T. pacificus* yield until about 1970 (Fig. 1). The autumn population has its highest density from the central waters offshore to the coast of the Asian continent in the Sea of Japan. With a rapid increase in yield due to the development of offshore fishing grounds in the Sea of Japan since 1970, the autumn population has become the main object of *T. pacificus* fishing in Japan (Fig. 1). The summer population is a local one, with the narrowest distribution of the three and a relatively low stock size.

T. pacificus in the Pacific

Fig. 2 shows the results of the grid surveys carried out in August and September between 1968 and 1978, when the distribution of *T. pacificus* spreads to the extreme north. The surveys in 1968 and 1969 were made by a single research vessel and the area covered was accordingly smaller than in other years. The data indicate a high density of *T. pacificus* from east of Hokkaido to the coast of the southern Kuril Islands, with a decrease in the offshore area. The abundance was highest in 1968 and 1969, but has decreased remarkably since 1973. Fig. 3 is a contour map obtained by connecting equal points of CPUE (number of squid caught per jigging machine per hour). Following the method shown in Table 1, I calculated the stock index (N) and the density index (F) for *T. pacificus* in each of eight years. N was highest in 1968 and was remarkably small in the years between 1973 and 1979, and the same is true for F (Table 2). N and F correspond reasonably well to the periodic change in the annual yield of *T. pacificus* (Y in metric tons) in the northern fishing ground (Fig. 4). These results give the following relationship:

$$\begin{aligned} Y &= 44.7 N + 3,250 & (r=0.996) \\ Y &= 121,000 F + 19,900 & (r=0.995) \end{aligned}$$

Two limitations regarding these relations must be mentioned. First, since the area covered in 1968 and 1969 was about 20% of

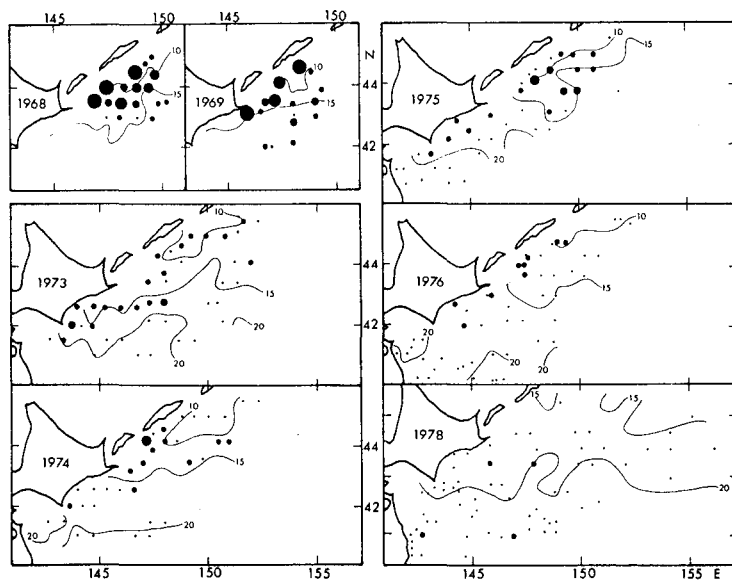


Figure 2. Number of *T. pacificus* per jigging machine per hour, and horizontal distribution of water temperature ($^{\circ}\text{C}$) in August–September for waters off northeastern Japan.

• : 0 • : less 10 • : 10–30 • : 30–50 • : 50–100 • : over 100

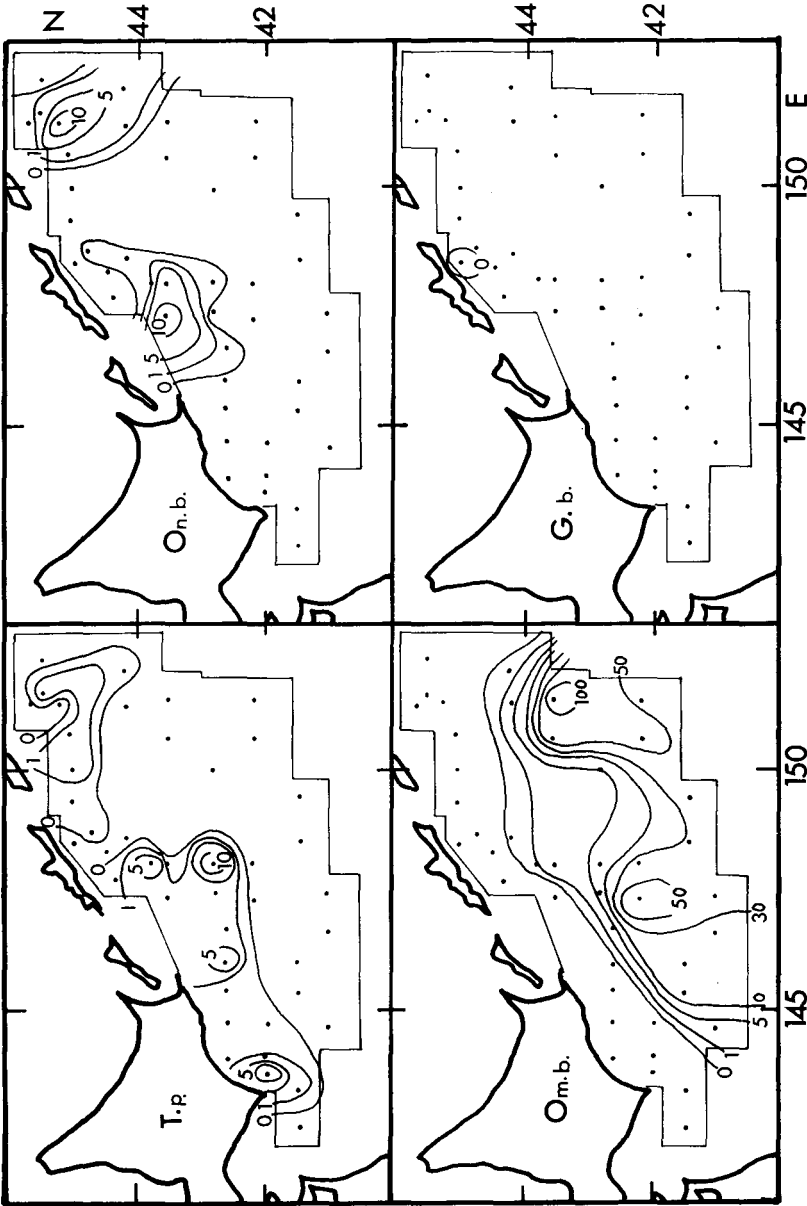


Figure 3. Densities of distribution for four oceanic squids per hour in August–September of 1973 off northeastern Japan. T. p., *Todarodes pacificus*; Om. b., *Onmastrephes bartramii*; On. b., *Onychoteuthis borealijaponica*; G. b., *Gonatopsis borealis*.

Table 2

Annual changes of stock size index (N) and density index (F) of three oceanic squids based on the grid survey in the waters off the Pacific coast of northeastern Japan in August–September of 1968–1979 (from Murata et al., 1976, and data of Hokusuiken).

Species	Index	Year							
		1968	1969	1973	1974	1975	1976	1978	1979
<i>T. pacificus</i>	$N \times 10^2$	104.5	80.5	7.8	5.1	21.1	1.0	0.5	0.3
	F	38.06	28.06	0.72	0.61	3.06	0.12	0.04	0.02
<i>O. bartrami</i>	$N \times 10^2$	5.6	3.7	144.0	47.6	75.9	139.1	199.7	151.7
	F	2.05	1.29	13.30	5.72	11.01	16.51	15.23	10.84
<i>O. borealijaponica</i>	$N \times 10^2$	8.9	3.4	7.2	40.9	28.5	47.95	6.7	6.7
	F	3.23	1.17	0.67	4.91	4.12	5.69	0.51	0.48
Surveyed area (A)		275	287	1,033	832	690	842	1,311	1,400

that covered in 1973 to 1979, the N for the first two years is probably underestimated. Second, the Sea of Okhotsk, where the abundance of the squid is high, was not included. Yield is based on squid caught by many boats during the months from June to December in the Pacific including the Sea of Okhotsk.

T. pacificus in the Sea of Japan

Fig. 5 illustrates the results of the grid surveys carried out in May and June in 1973, which correspond to the early part of the northward migration period, and in August and September of the same year, which correspond to the early period of southward migration. These data demonstrate that the main distribution of *T. pacificus* is in the center of the Sea of Japan in May and June, and along the coast of Asia in August and September.

N and F values were also calculated, based on the grid surveys carried out during May–June and August–September in 1971 to 1979. (Table 3). The relationship between Y and N is shown in Fig. 6. Since the surveys in waters near the coast of the continent were limited, the stock size indices are shown in two ways. N (N_1 , N_2) refers to the index including these waters and N' (N'_1 , N'_2) is the case where they are excluded. N' accounts for 40–80% of N in May–June, and 20–50% in August–September. These ratios sug-

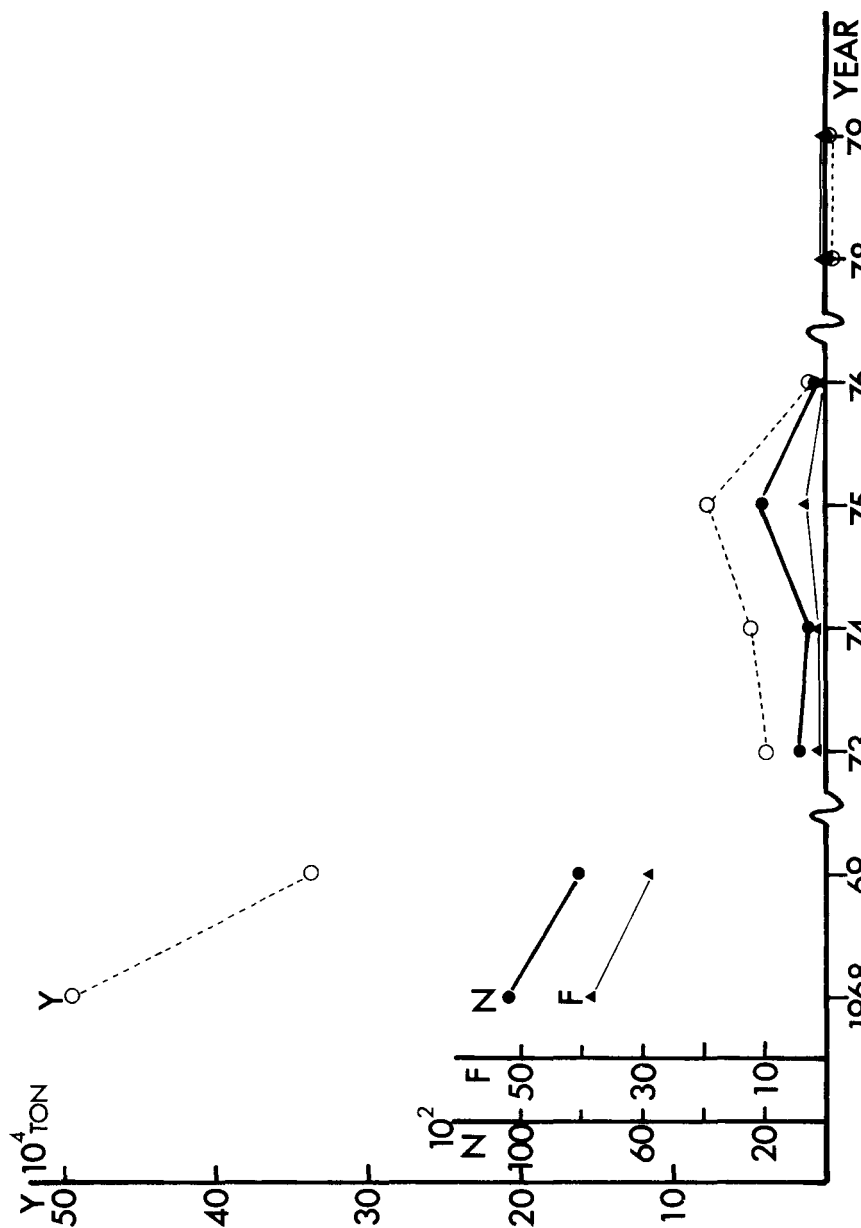


Figure 4. Annual changes of stock index (N), density index (F), and yield (Y) of *T. pacificus* in the waters off northeastern Japan (N , F from Table 2; Y from Table 4).

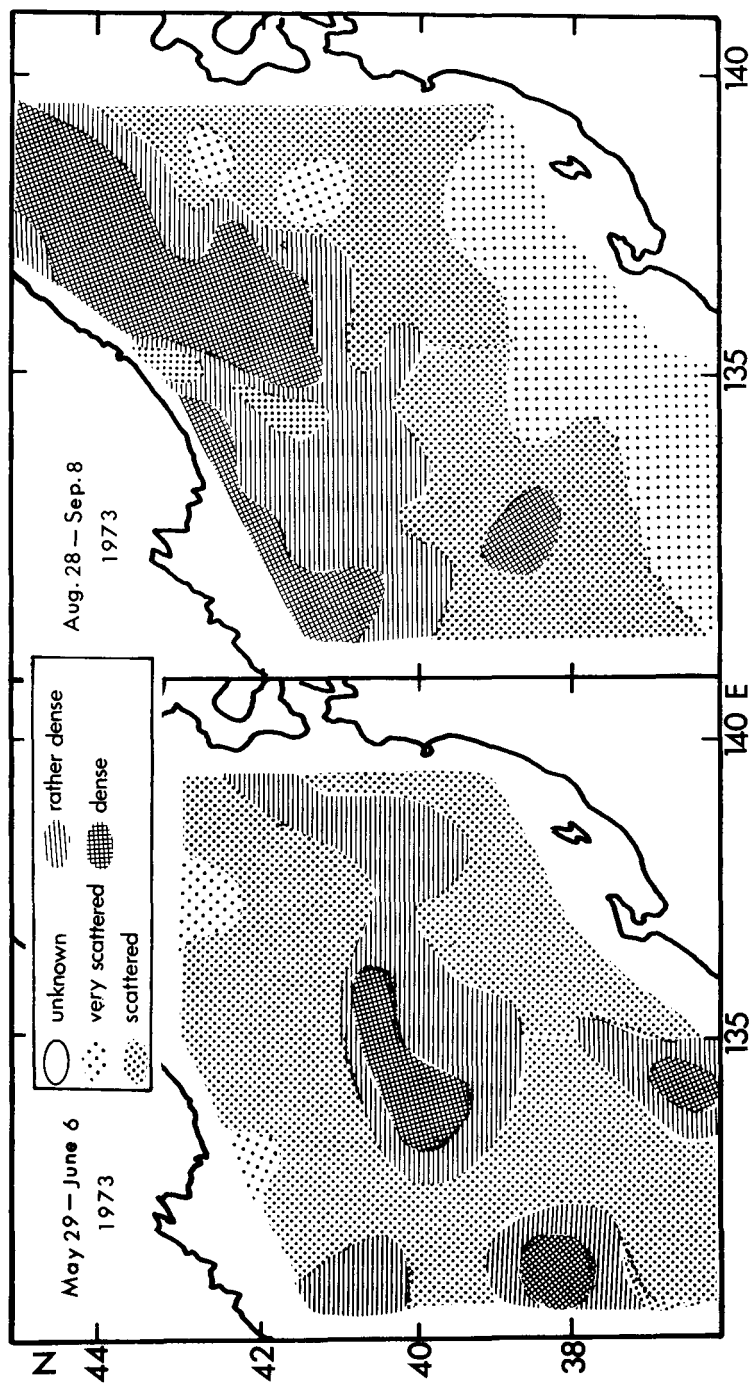


Figure 5. Distribution of *T. pacificus* by the grid survey in the Sea of Japan in 1973 (from Nisuiken Research Data, 73-01, 73-02, 1973).

Table 3
Annual changes of stock size index (N) and density index (F) of *T. pacificus* based on the grid survey in the Japan Sea in 1971–1979.

Year	May-June				August-September			
	Survey Area 1.		Survey Area 2.		Survey Area 3.		Survey Area 4.	
	$N_1 \times 10^3$	F_1	$N'_1 \times 10^3$	F'_1	$N_2 \times 10^3$	F_2	$N'_2 \times 10^3$	F'_2
1971	100.9	58.0	40.5	36.8	67.2	28.6	32.4	25.2
1972	61.0	36.7	31.4	28.5	66.6	28.4	29.0	22.5
1973	38.7	22.7	22.9	20.8	71.9	30.6	14.7	11.4
1974	32.7	23.6	27.9	25.4	57.3	24.4	26.4	20.5
1975	40.3	26.9	25.2	22.9	49.3	21.0	15.3	11.9
1976	29.6	19.3	20.6	19.6	29.3	14.6	10.8	11.1
1977	—	—	11.4	12.3	—	—	12.9	10.0
1978	—	—	14.3	13.0	—	—	14.8	11.6
1979	20.8	16.4	18.4	16.7	36.0	15.4	12.9	10.0

(From Kasahara, 1978, and Nisuiken Research Data, 79-01, 79-02, 1979.) Survey area: (1) south of 42°N, (2) south of 42°N exclusive of the 200-mile limits of the USSR and North Korea, (3) south of 45°30'N, (4) south of 45°30'N exclusive of the 200-mile limits of the USSR and North Korea.

gest that the distribution of *T. pacificus* shifts from central waters towards the continental coast during June and September. N values of the May–June and August–September periods correspond roughly to the periodic change of Y after 1972 (Fig. 6). The following relationship was obtained:

$$\begin{aligned}\text{May-June, } Y &= 2.77 N + 140,000 \quad (r=0.869) \\ \text{August-September, } Y &= 2.06 N + 137,060 \quad (r=0.797)\end{aligned}$$

***O. bartrami* and *O. borealijaponica* in the Pacific**

With the decrease in the stock of *T. pacificus*, fishing for oceanic squid such as *O. bartrami* has increased (Table 4). It is known that *O. bartrami* is widely distributed in warm waters all over the world (Okutani, 1973). Remarkable increases have occurred in the number of fishing boats and in the extension of fishing grounds since squid boats began to catch this species in 1974. Until 1977, *O. bartrami* was caught by jigging between August and November. However, since 1978 drift gillnets have also come into use. This

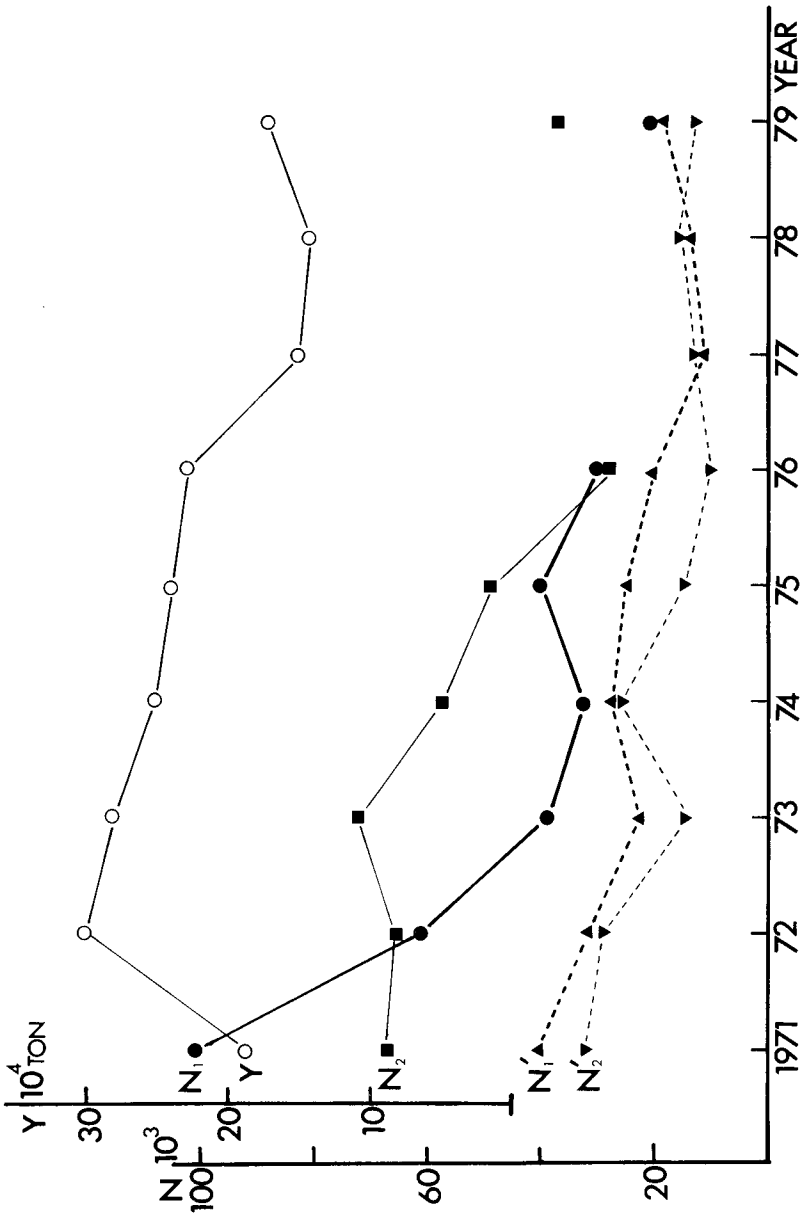


Figure 6. Annual changes of stock size index (N), density index (F) and yield (Y) of *T. pacificus* in the Sea of Japan. N_1 , N'_1 ; in May-June (from Table 3); N_2 , N'_2 ; in August-September (from Table 3).

Table 4
Annual yields of *T. pacificus*, *O. bartramii*, and *O. borealijaponica* in the waters off the Pacific coast of northeastern Japan.

Species	Year										
	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
<i>T. pacificus</i>	492,973	337,132	178,994	111,971	172,206	38,317	48,416	77,249	9,507	6,543	4,460
<i>O. bartramii</i>	0	0	0	0	0	0	17,000	41,000	84,000	121,800	151,300
<i>O. borealijaponica</i>	0	0	0	0	750	60	5,000	0	2,581	12	67

Units are tons.

species grows from 30 to 50 cm in mantle length, and from 1 to 4 kg in body weight (Murata and Ishii, 1977; Naito et al., 1977a). They feed mainly on small fish such as myctophids (Naito et al., 1977b).

O. borealijaponica has not been a main objective of fishing because of its relatively low market price, but it has been landed along with the other two species. Information on the ecology of *O. borealijaponica* is poor. They may grow to about 30 cm in mantle length, and about 500 g in body weight (Murata and Ishii, 1977; Naito et al., 1977a). They feed on euphausiids, amphipods, and small fish (Naito et al., 1977b).

These two species were also caught in the Pacific grid survey. *O. bartrami* was widely distributed in the area studied, mainly in waters warmer than 15°C (Fig. 7). *O. borealijaponica* was densely distributed in waters from 10° to 15°C (Fig. 8). From these results, the stock size (N) and the density (F) indices were calculated (Table 2). Fig. 9 shows the relationship between N and F for the species and their annual yields (Y in metric tons). The periodic changes in N and F are closely related to each other, but they do not always show good correspondence with the yield. This can be explained by the fact that the research area covers only part of the main distribution of the two species and that the yield does not always reflect the overall abundance. However, N and F for *O. bartrami* correspond well with Y in 1974 and 1975, and in 1978 and 1979 when the range of the fishing grounds was almost the same.

Discussion

Assessment of the stock sizes of underexploited species of squid is a first step in developing them as resources. The methods of fishing for cephalopods are very diverse (Voss, 1973). However, I think that jigging is the best method for quantitatively fishing for oceanic squid.

The fishing grounds of *T. pacificus* cover most of the main distributional areas and fishing effort has been extremely large in recent years (Okutani, 1977; Doi and Kawakami, 1979; Murata and Araya, 1977). Annual yields of *T. pacificus* in the Pacific correspond well to both the change in abundance in this area and to the stock sizes of the winter population in the waters around Japan (Murata

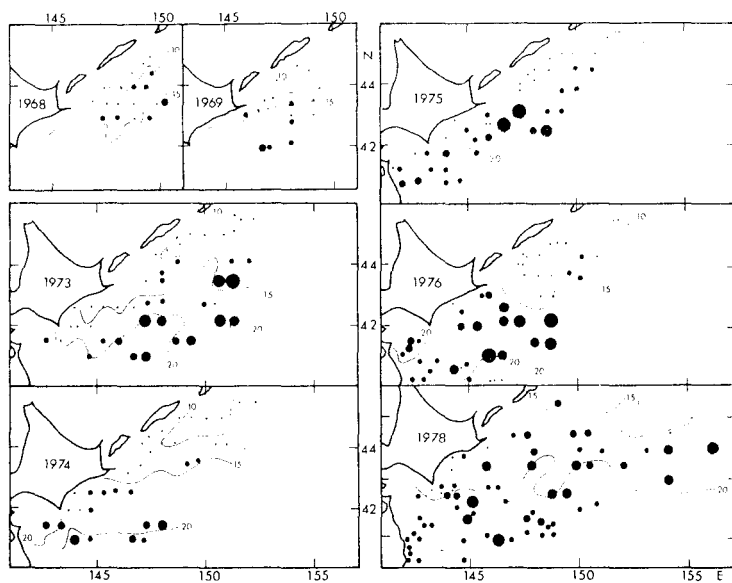


Figure 7. Number of *O. bartrami* per jigging machine per hour, and horizontal distribution of water temperature ($^{\circ}\text{C}$) in August–September for waters off northeastern Japan. See Fig. 2 for legend.

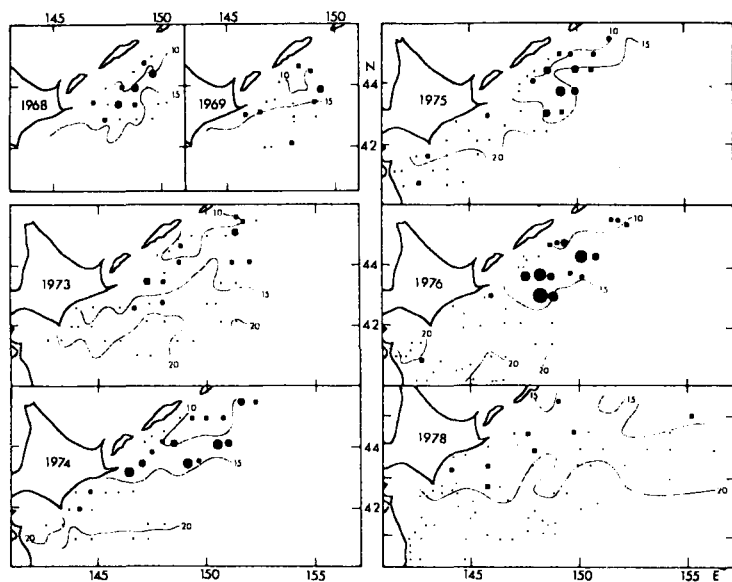


Figure 8. Number of *O. borealijaponica* per jigging machine per hour, and horizontal distribution of water temperature (°C) in August–September for waters off northeastern Japan. See Fig. 2 for legend.

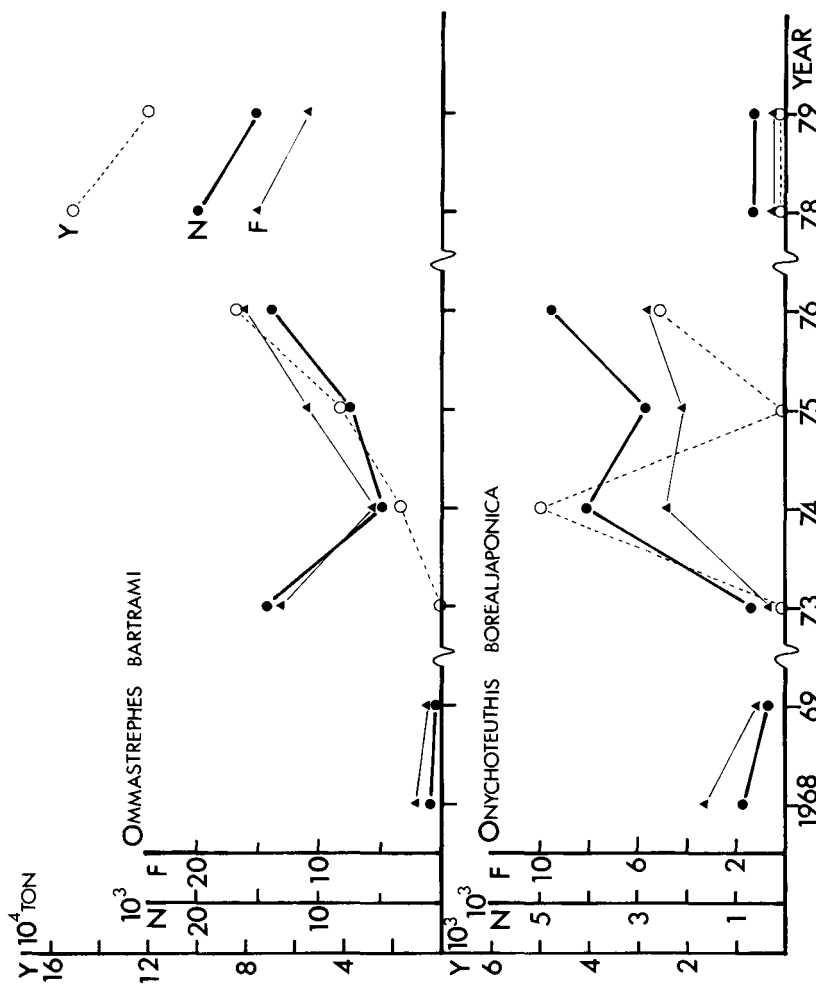


Figure 9. Annual changes of stock size index (N), density index (F), and yields (Y) of two oceanic squids in the waters off northeastern Japan (N , F from Table 2; Y from Table 4).

and Araya, 1977). Stock sizes of the winter population have been at extremely low levels since 1973. Doi and Kawakami (1979) suggest that the stock of the winter population has decreased by about 85% in the past 10 years. This view is in agreement with the changes of N and F shown in Fig. 4. Most of the yield since 1971 in the Sea of Japan is thought to be from the autumn population. Since yield per fishing day per boat has decreased as fishing effort increased since 1971–1972, the autumn population has declined in size in recent years (Okutani, 1977). This trend corresponds roughly to the changes of N and F shown in Fig. 6.

Both the number of fishing days and the yield of *O. bartrami* during 1976 and 1978 have increased, but yield per fishing day per boat has decreased (Table 5). The number of squid caught per fishing day per boat reached a high in 1977 and decreased in 1978 to a level lower than in 1976. The yield and yield per fishing day per boat in 1979 were below those in 1978. These data suggest that the stock size of *O. bartrami* in 1979 has decreased to a level lower than in 1978, as shown by N and F in Fig. 9. Judging from these results, I believe that it is possible to assess the abundance of *T. pacificus* and *O. bartrami* in the waters around Japan based on the results of jigging surveys by several research vessels.

The relationship between the density indices (F) of *T. pacificus* and *O. bartrami*, as obtained in the grid surveys in the Sea of Japan and the Pacific, and their respective yield (Y) is shown in Fig. 10. In the case of *T. pacificus*, Y varied from 170,000 to 490,000 metric tons when F ranged between 16 and 38, and Y was 4,000 to 80,000 tons when F was between 0 and 3. Here, Y s were based on the yield obtained through considerable fishing efforts in the main area of distribution during the period May–December. Y for *O. bartrami* ranged from 20,000 to 150,000 tons for values of F between 6 and 17. The following relationship between F and Y (in tons) for both species was obtained:

$$Y = 10,500 F + 16,300 \quad (r = 0.972)$$

It is noteworthy that such a high positive correlation was found between F and Y calculated from different species in different waters. While more study is necessary to determine the general appli-

Table 5
Fishing days, yields, and catches per fishing day per boat for
O. bartrami by fishing boats over 30 tons from Aomori Prefecture in July-October.

Year	Fishing days	Yields (ton)	Catches (10* individual)	Mean body weight of squid (g)	Yields (Kg) per fishing day	Catches in number per fishing day
1976	13,133	28,958	33.8	857	2,205	2,574
1977	33,095	58,725	101.5	579	1,774	3,067
1978	48,855	64,301	114.6	561	1,316	2,346

(From data of Aomori Prefectural Fisheries Experimental Station.)

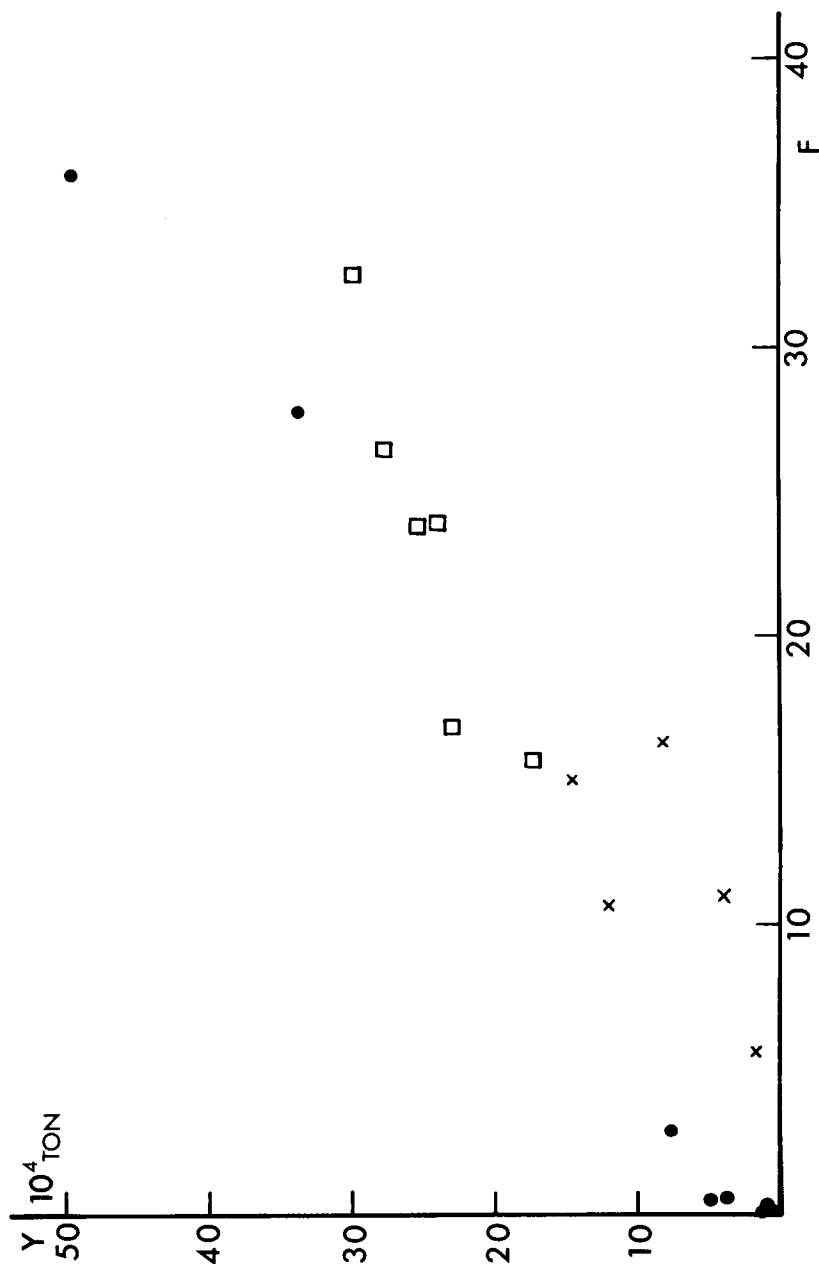


Figure 10. Relationship between density index (F) and yield (Y) of two oceanic squids, \square *T. pacificus* in the Sea of Japan in 1972-1979 (F , average of May-June and August-September from Table 3), \bullet *T. pacificus* in the waters off the Pacific coast of northeastern Japan in 1968-1979 (F from Table 2; Y from Table 4), \times *O. barrami* in the waters off the Pacific coast of northeastern Japan in 1974-1979 (F from Table 2; Y from Table 4).

cation of this correlation, I hope it can be used to assess the stock size or potential yield of unexploited oceanic squid. F should be calculated for all the main distribution areas of the species in question so that Y will correspond to the largest possible yield obtainable through maximum fishing effort.

Squid and cuttlefish generally are attracted to small objects moving in the water. This behavior is used to advantage in squid jigging, but it is likely that it varies among species and among different stages of growth within the same species. For example, *T. pacificus* caught by jigging are mostly 12 to 25 cm in dorsal mantle length, from immature to adult stage (Araya, 1967); however, it is difficult to catch either juvenile squid below 11 cm or mature females in large numbers by jigging. While the yield of *O. bartrami* by jigging generally shows a rapid decrease after November, a large yield was obtained by drift gillnets in almost the same fishing ground at this time of the year in 1978. One reason for this may be a change of feeding habits then. Squid jigs used for *O. bartrami* are larger in size than those for *T. pacificus*. Thus, the effectiveness of jigging should be studied on squid from immature to the adult stages and at different stages of feeding activity. Furthermore, biological characteristics of the species in question must also be considered in order to determine the best size for jigs and the best method of jigging.

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